Impact Analysis of NASA Earth Science Applications Project

Enhancing USAID Malaria Early Warning Systems with NASA Earth Science Results

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Prepared for:

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Executive Summary

The NASA Applied Sciences Program supports efforts to discover and demonstrate innovative and practical uses of NASA Earth science data and knowledge. The program funds applied science research and applications projects across a range of themes to enable near-term uses of NASA Earth science by public and private organizations.

In 2005, the program initiated a score of projects selected under an open, competitive solicitation.[1] One of the projects — *Enhancing USAID Famine and Malaria Early Warning with NASA Earth Science Results* — collected environmental data from NASA space-based platforms and integrated it into the United States Agency for International Development's (USAID) Malaria Early Warning System (MEWS) to improve malaria-control decision support to public health organizations. At the conclusion of the project in 2008, improved MEWS forecasts were available to public health organizations for malaria mitigation planning and operations.

The Applied Sciences Program subsequently assembled an analytic team to estimate the immediate impacts of the project. The team compared malaria cases (morbidity) and deaths (mortality) for 2008-2009, after integration of the NASA Earth observations into MEWS, to projections based on historical trends prior to 2008. For comparison, the team developed a second impact estimate by eliciting estimates from subject matter experts. The experts provided consensus estimates of the fraction of the observed reductions in malaria cases and deaths between 2007 and 2009 that might reasonably be attributable to the NASA project. The team also sought data to identify any reductions in malaria control costs that occurred after the completion of the NASA project.

The team collected and analyzed malaria rates in Botswana from 1997 to 2009. Botswana was chosen for analysis due to the high quality of malaria mortality and morbidity data available for the country, and the opinions of subject matter experts that the country had sufficient physical and political infrastructure to make use of the insights provided by the NASA Earth observations.

The analysis results demonstrated a decreasing trend in malaria cases and deaths over the period 1997-2009, reflecting Botswana's effective programs to reduce the threat of the disease. The analytic team could not, however, detect a statistically significant difference between cases or deaths for 2008 and 2009 compared with predictions based on data from 1997–2007, before the NASA project was completed. For 2008, both case and death figures were slightly above the predicted amount, as was the 2009 data for cases. The team concluded that Botswana's successful efforts to control malaria improved the infection and death rates to such a low level that the incremental impact of the added NASA Earth observations was not distinguishable from normal variation of those rates in the available data. While results of the analysis regarding benefit attributable to NASA were not statistically significant, the analysis demonstrates both a potential approach to analyzing such benefits, as well as difficulties of analyses for health projects. Further data collection could allow the Applied Sciences Program to use more robust time-series methodologies to identify the effects of the NASA Earth observations on MEWS.

The expert opinion analysis resulted in an estimate that as much as 10 percent of the drop in mortality and morbidity in Botswana after the NASA Earth observations were available might be attributable to the NASA project. The expert opinion-based parameter analysis suggested a reduction of approximately 105 cases per year as an upper limit for the impact of the NASA project in Botswana. Cost-reduction data were incomplete and inconsistent, and did not indicate a clear trend in effectiveness of malaria control expenditures.

Analysis to extend the comparative impact and expert opinion methodology to all of sub-Saharan Africa was limited by data availability. The analysis resulted in potential impact estimates ranging from approximately 665,000 to 6.9 million cases of malaria avoided per year.

[1] NASA Cooperative Agreement Notice NN-H-04-Z-YO-010-C "Decision Support through Earth Science Research Results"

Introduction

A. NASA Applied Sciences Program

The NASA Applied Sciences Program supports the Earth Science Division within the NASA Science Mission Directorate. The overarching purpose of the Applied Sciences Program is to discover and demonstrate innovative uses and practical benefits of NASA Earth science data, scientific knowledge, and technology.

The Program funds applied science research and applications projects to promote innovation in the use of NASA Earth science for near-term societal benefits. Overall, the Applied Sciences Program serves as a bridge between the data and knowledge generated by NASA Earth science activities and the information and decision-making needs of public and private organizations. To this end, the Program increases the benefits to society of the Nation's important investments in NASA Earth science.

The Applied Sciences Program primarily works through partnerships with public and private organizations that want to improve their internal decision-making activities and/or the products and services they provide their constituents and customers. Where NASA Earth observations and modeling capabilities are evaluated to have potential application, NASA and the partner organizations collaborate to test and integrate the data and modeling capabilities into the decision making and/or products and services. These collaborations involve appropriate academic, business, nonprofit, and other entities to accomplish the project and extend the results.

B. Decisions-04 Solicitation and the Enhancing USAID Famine and Malaria Early Warning with NASA Earth Science Results Project

In 2005, the program initiated a score of projects selected under an open, competitive solicitation[2] to extend the societal and economic benefits of NASA research in Earth science, information, and technology. One of the projects was *Enhancing USAID Famine and Malaria Early Warning with NASA Earth Science Results.*

The objective of the *Enhancing USAID Famine and Malaria Early Warning with NASA Earth Science Results* project was to improve malaria-control decision support to public health organizations by integrating NASA Earth observation and modeling results into the USAID's MEWS. MEWS provides 10-day precipitation estimates to malaria program planners, enabling the identification of areas with unusually high rainfall as candidates for malaria outbreaks. Early warning systems such as MEWS can assist health services organizations to target their resources to prevent and control malaria within epidemic-prone areas. Forecasts of environmental factors can be used to identify regions where outbreaks are likely to occur. These forecasts of high-risk areas can provide warnings of potential epidemics many months in advance, allowing officials to concentrate staff and resources to areas most likely at risk for an outbreak.

C. Challenges Addressed by the Enhancing USAID Famine and Malaria Early Warning with NASA Earth Science Results Project

About 3.3 billion people—half of the world's population—are at risk from malaria.[3] The disease claims the lives of more than 1 million people every year, the majority of whom are under five years of age, and it infects an estimated 500 million people annually.[4] Although endemic in several regions of the world, the disease is most widespread in Africa, where an estimated 90 percent of cases occur.[5]

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[2] NASA Cooperative Agreement Notice NN-H-04-Z-YO-010-C "Decision Support through Earth Science Research Results"

[3] World Health Organization, "Facts on File: 10 Facts about Malaria", http://www.who.int/features/factfiles/malaria/en/index.html (obtained June 19, 2010).

[4] Jeffrey Sachs and Pia Malaney. "The economic and social burden of malaria." *Nature,* Volume 415, (February 2002): 680-685.

[5] *Ibid*.

Public health officials in many nations where malaria is endemic have limited financial resources and staff, and so are not able to implement preventative measures across entire vulnerable populations. Agencies such as the USAID provide some humanitarian assistance to vulnerable populations facing disasters or epidemics such as malaria, but this assistance must likewise be geographically targeted if it is to be effective.

Early warning systems can assist health programs and service organizations in targeting resources for preventing and controlling the disease in epidemic-prone areas. Observations and forecasts of environmental factors such as temperature, rainfall, vegetative cover, and soil moisture can be used to identify specific regions where outbreaks are likely to occur, in part because of the relationship between these factors and the mosquito life cycle. This information about probable high-risk areas can be used by health professionals and program managers to deploy staff and resources more effectively in their mitigation efforts.

1. The NASA Project to Enhance MEWS

A. Project Description

One widely used early warning system is the MEWS, supported by USAID and NASA. MEWS provides 10-day precipitation estimates based upon data and models from the U.S. Climate Prediction Center. These estimates are available through the MEWS web interface[6] for consecutive 10-day periods from December 6, 1999, through the present. Malaria program planners can download data and create time series to compare recent rainfall levels with historical averages. Areas with unusually high rainfall are candidates for malarial outbreaks.

In 2005, the NASA Applied Sciences Program awarded a three-year grant for a project titled "*Enhancing USAID Famine and Malaria Early Warning with NASA Earth Science Results*." The project's objective was to improve malaria-control decision support to public health organizations by integrating NASA Earth observation and modeling results into MEWS. Specifically, the goals of the project were to:

- Provide near real-time satellite-derived remote sensing information about weather and climate that will impact malaria mosquito vectorial capacity estimates
- Develop and test useful information products appropriate to improving epidemic malaria control
- Make these products available through the Internet to better support malaria control experts in the field

Prior to the project, experts obtained much of the malarial early warning data through locally observed meteorological data and ground samplings. The ability to obtain consistent and complete data by such direct observation in many malaria-prone areas was limited due to the amount of resources, staff, and equipment needed to monitor millions of square kilometers of remote or sparsely populated regions. Observations from aircraft were similarly expensive. However, Earth observations from space represent a potentially cost-effective data source.

A wide range of space-based platforms routinely make environmental observations, but not all of these data are fully integrated into existing predictive models for malaria-prone regions. The NASA project sought to augment these data by integrating a variety of satellite-derived rainfall and temperature data into MEWS to improve early warning systems in sub-Saharan Africa.

The project, concluded in 2008, provided real-time rainfall, temperature, vegetation and humidity data for the existing MEWS vectorial capacity model. Historical data for rainfall, precipitable water and humidity from NASA datasets were also integrated into a model of mosquito behavior. The model enabled public health officials to develop forecasts of mosquito activity, which they then

[6] http://iridl.ldeo.columbia.edu/maproom/.Health/.Regional/.Africa/.Malaria/.MEWS/

used to issue risk warnings up to five months before the peak malaria season and four months earlier than predictions based on actual rainfall.[7]

B. Potential Benefits

Figure 1 below shows the flow of potential benefits associated with this project, as identified in interviews with principal investigators and other members of the MEWS user community.[8] As a result of this project, NASA information flows into the MEWS, potentially leading to more accurate estimates of rainfall and other malaria-relevant environmental factors. These improved forecasts could lead to more effective decisions on targeting specific geographic areas with preventative measures. As a result of these more effectively targeted measures; there could be fewer cases of malaria, fewer deaths from malaria, and an improvement in economic factors that contribute to material well-being.

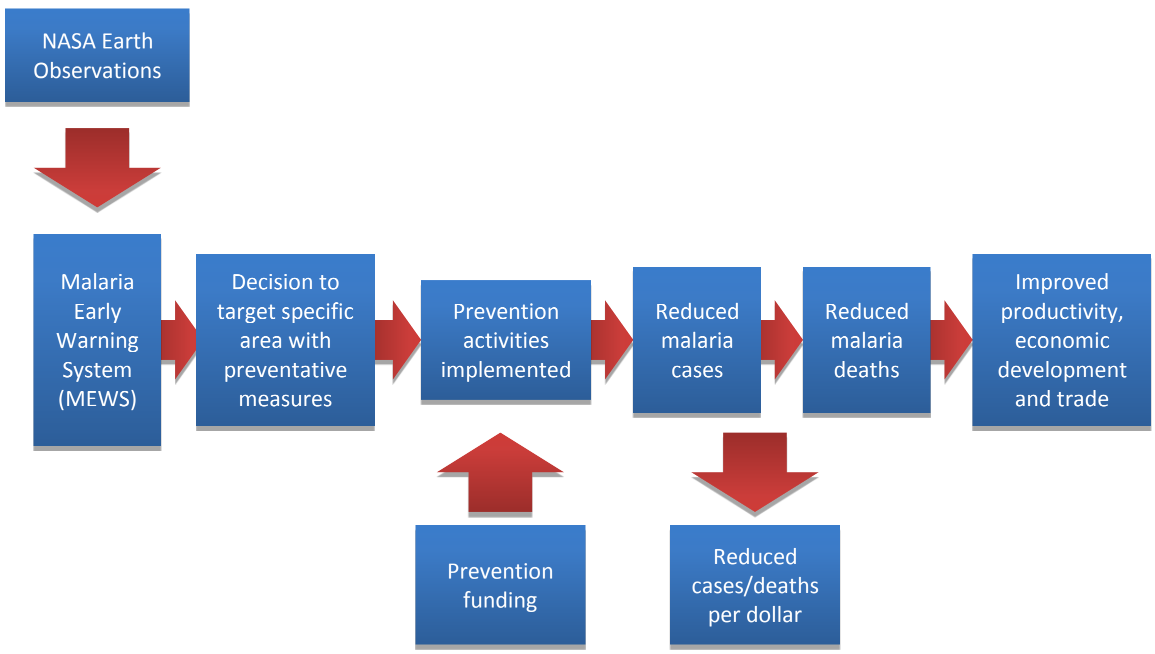


Figure 1: Potential Benefits Flow from NASA Earth Observations Entered into MEWS

In general, the benefits are related to improved physical and economic wellbeing as a result of a lower incidence of malaria. The specific, quantifiable benefits identified in the interviews include:

A. Reductions in the number of malaria cases ("morbidity")

B. Reductions in the number of deaths from malaria ("mortality")

C. Improved targeting of malaria prevention resources ("resource efficiency")

D. Reductions in the cost/spending per case avoided for malaria programs ("cost efficiency")

E. Increases in productivity, economic development, and trade as a result of decreased mortality and morbidity, and of decreased resources needed for the care of the sick and dying ("economic impacts")

[7] NASA Applied Sciences Program & Public Health, "NASA and Malaria Early Warning Systems: Using NASA Data to Combat Epidemics," FS-2008-06-144-LaRC. http://science.nasa.gov/media/medialibrary/2010/03/31/MEWS_R1.pdf

[8] Interview with Principal Investigators at USGS EROS Data Center on March 19, 2010.

The next section addresses how the team quantitatively estimated the benefits of this project.

2. Methodology for Quantitatively Estimating the Societal Benefits of the Project

A. Analysis Overview

As part of a post-project review, the NASA Applied Sciences Program assembled an analytic team to perform a quantitative evaluation of the impact of the data integration project. Their analysis of the project focused on obtaining an initial estimate of reduced mortality, reduced morbidity, and improved cost efficiency impacts. Since there are at least two other benefit categories, as listed in the previous section, the analysis results provide a minimum value for the total benefits of the NASA program.

A wide range of analytic techniques is available to estimate impacts and benefits, including retrospective economic valuations such as benefit-cost analyses, prospective estimations such as Value of Information approaches, and expert-based approaches such as Delphi methods. The technique used depends upon the situation at hand.

In choosing among these methods, the analytic team noted that the NASA project was successfully integrated into real-world decision support through MEWS, so that at least some retrospective data were available. Based on the availability of this data, the team chose to use an impact analysis methodology that compared real-world direct metrics—such as the number of reported malaria cases, reported deaths, and spending per person—for 2008 and 2009 (the years after project completion) with a forecast of these factors based on historical trends prior to project completion in 2008.

While proceeding with the impact analysis approach, the team noted that only two years of post-implementation data would be available, namely 2008 and 2009; thus, statistical means could not be used to isolate the specific effects on such a small set of observations. Additionally, historical malaria rate data have relatively high variance, which makes it difficult to make strong statistical statements for relatively small impacts. The team compared these limitations against the strong credibility of actual data as compared to *a priori* estimates, as well as the difficulty in obtaining detailed decision maker data needed for most Value of Information (VOI) approaches, and chose to supplement the comparative approach with expert opinion analysis.

The team elicited estimates from subject matter experts on the fraction of the observed reductions after 2007 that might reasonably be attributable to the project. Due to the limited availability of access to in-country experts, the expert-opinion approach was planned as a validation of the comparative impact approach results.

To analyze the impacts on malaria mitigation cost effectiveness, the team reviewed the historical annual expenditures on mitigation measures and actual annual reductions in cases and deaths, comparing the ratio before and after the completion of the project. While data were sparse and the results inconclusive, they are presented here to provide insight into the magnitude of expenditures per case or death avoided.

As a final extension of the benefits analysis, the team applied the impact findings and approaches from the original study area to the larger sub-Saharan region to estimate the potential impact of the program on the larger area.

B. Comparative Impact Analysis Using Historical Data

Figure 2 illustrates the concept of the comparative impact approach the team used to analyze the impact of new information on a malaria mitigation program. The team considered two cases: one in which the NASA information was made available to decision makers through MEWS, and one in which it was not. In each case, decision makers were assumed to make their best decisions with the information at hand, which would result in potentially different outcomes. The difference between the two outcomes represented the net benefit to the program of making the NASA Earth observations available.

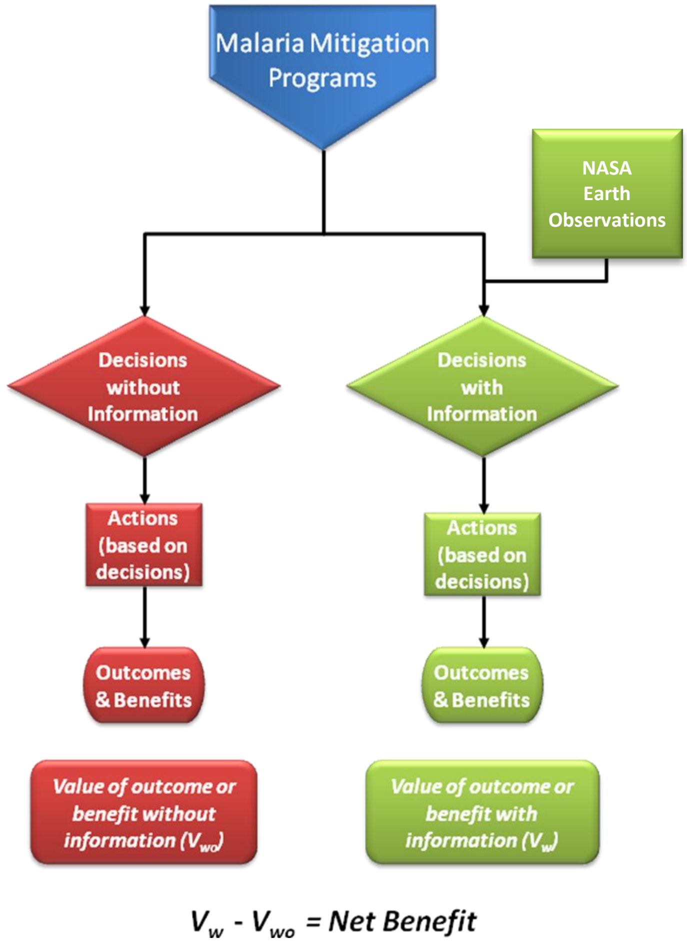


Figure 2: Comparative Impact Methodology for Estimating Societal Benefits

An obvious challenge is that only one of the cases actually took place: the NASA Earth observations were, in fact, provided to the decision makers. The analysis thus required a prediction of the behavior of the decision makers in the counterfactual case, in which the NASA information was not available. To assess the counterfactual case, the analytic team used time-series methods to create a forecast model of outcomes based on historical data from years prior to the integration of the NASA Earth observations. The team compared the model forecasts with the actual observations to derive the net benefit. A key assumption in using the counterfactual model is that other factors did not contribute significantly to the difference between forecast and observation.

As an example of the counterfactual model methodology in a malaria context, consider the situation shown in Figure 3. A program manager might have a fixed budget to spend on malaria control measures in the hypothetical region depicted by the map at the top of the figure. The map's color contours show areas of increasing malaria risk, which are not fully known to the program manager. Using only prior information and experience, and without the NASA Earth observations, the program manager develops plans to treat the area within the dashed lines in the top map. Based upon historical data, existing models, population growth, and other known factors, this targeted treatment is projected to be somewhat effective, keeping the number of new malaria cases down to 1000 and the deaths down to 10 in the region.

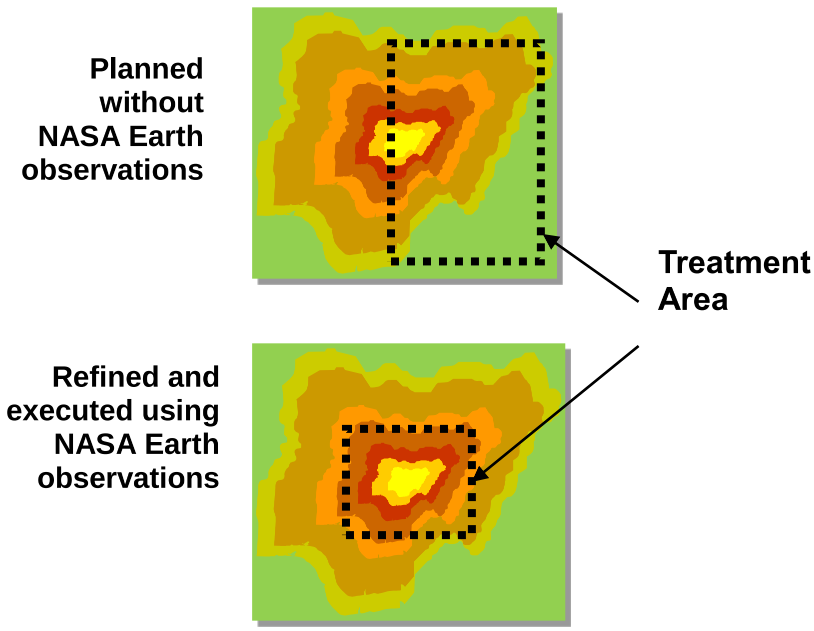


Figure 3: Example of Comparative Impact Analysis, Malaria Control Measures

In an alternative scenario, the program manager is able to access data products supplied as a result of the NASA project, resulting in improved knowledge about the threat contours. The program manager is then able to more effectively manage the size and location of the treatment area, as shown in the bottom map, resulting in treatment of more high-risk areas and fewer funds expended in low-risk areas. After this better-focused approach is completed, there are 10 cases and no deaths in the region for the year.

In this illustration, the impact of the NASA project is equal to the difference between the "without information" and "with information" cases; that is:

- Net Impact of Information on Number of Cases = 1,000 – 10 = 990 case reduction
- Net Impact of Information on Number of Deaths = 10 – 0 = 10 death reduction

This impact comparison requires knowledge of two different scenarios: one without the improved forecasts, and one with them. Since only one scenario is possible, the other scenario must be projected using modeling, expert opinion, or some other analytic method. In this example, the scenario without improved forecasts resulting from integration of NASA Earth observations was projected based on historical data and modeling.

Note that, for the NASA project information to have value under this framework:

- There must be a linkage between the NASA information, a decision, a program action, and a socially valuable set of outcomes or benefits.
- The socially valuable benefits must be measurable in some meaningful way and must differ depending on which program action is taken.
- The information must have the likelihood of effecting a change in the decision made.

C. Expert Opinion Analysis of Impact Data

To address the possibility that confounding factors might be present, the analytic team developed a parallel set of estimates of the impacts by interviewing experts familiar with the project and its outcomes. The experts came primarily from the project team, as availability to in-country experts was limited.

The experts were provided with data on the observed changes between 2007 and 2009. A series of interviews was then conducted with project experts both on a one-to-one and group basis. They were initially asked where, based on their knowledge of the program, the expanded MEWS was most used. A majority agreed that Botswana was the heaviest user of the information, and was most likely to have the program infrastructure to be able to use the information. Not coincidentally, Botswana also has low levels of malaria infections and deaths relative to neighbors, which was expected to make the value of the additional NASA Earth observations relatively modest.

Once the experts reached consensus on the location issue, they were asked to estimate impact, in percentage terms (e.g., 0.1 percent, 5 percent, 15 percent), of the NASA Earth observations on the overall reduction in malaria in Botswana. Using a Delphi-like approach, the analytic team shared these individual results with the group to develop a consensus estimate on this number. The team then applied this fractional estimate to the observed changes to develop an estimate of the impacts.

D. Cost Effectiveness Analysis of Expenditures

To analyze the impacts on malaria mitigation cost effectiveness, the team obtained data on the historical annual expenditures on mitigation measures. They divided each year's expenditures by the actual annual reductions in cases to develop a ratio of expenditures per case avoided; that is, the effective cost of avoiding one additional case of malaria. They then compared the ratios before and after the completion of the project to assess any observable changes.

3. Analysis of Impacts

As mentioned previously, interviews with project staff during the expert opinion analysis suggested that the impact of the project would be most apparent in Sub-Saharan Africa, and that the most reliable malaria impact data would likely be that for Botswana. This assessment was based on historical experience suggesting that Botswana had relatively consistent data collection procedures, and that during the analysis period there were few confounding factors in Botswana (e.g., sudden land use changes, large migration of people, break down in law and order, or new local malaria reduction programs) that might be difficult to isolate from the project impact.

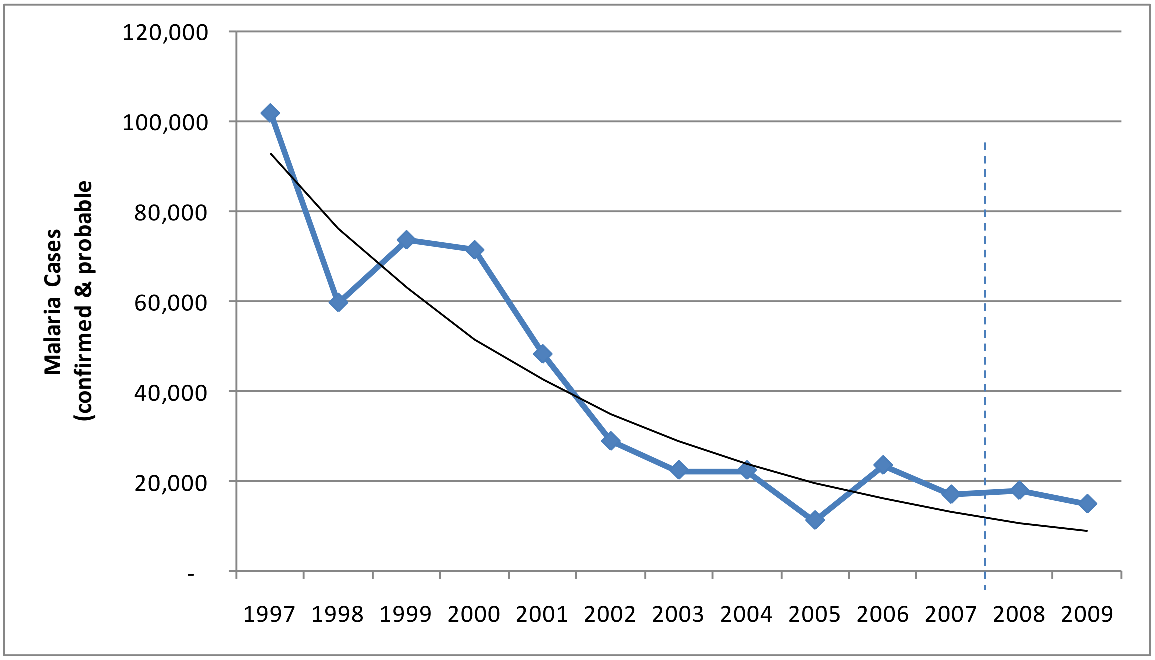
The analysis team collected and analyzed malaria rates in Botswana from 1997 to 2009 to determine the impact of the data integration project, and extrapolated the results within Botswana to 28 Sub-Saharan Africa countries to obtain a first-order estimate of the potential regional impact.

A. Comparative Impact Analysis

Figure 4 shows confirmed plus probable malaria cases and malaria deaths in Botswana from 1997 to 2009. The year 1997 was selected as the first year to consider in the modeling effort because it was the earliest date for which comprehensive data were available. The team obtained data from the World Health Organization's 2010 World Malaria Report,[9] There is a general trend downward, representing Botswana's significant effort to eliminate malaria by 2015.[10]

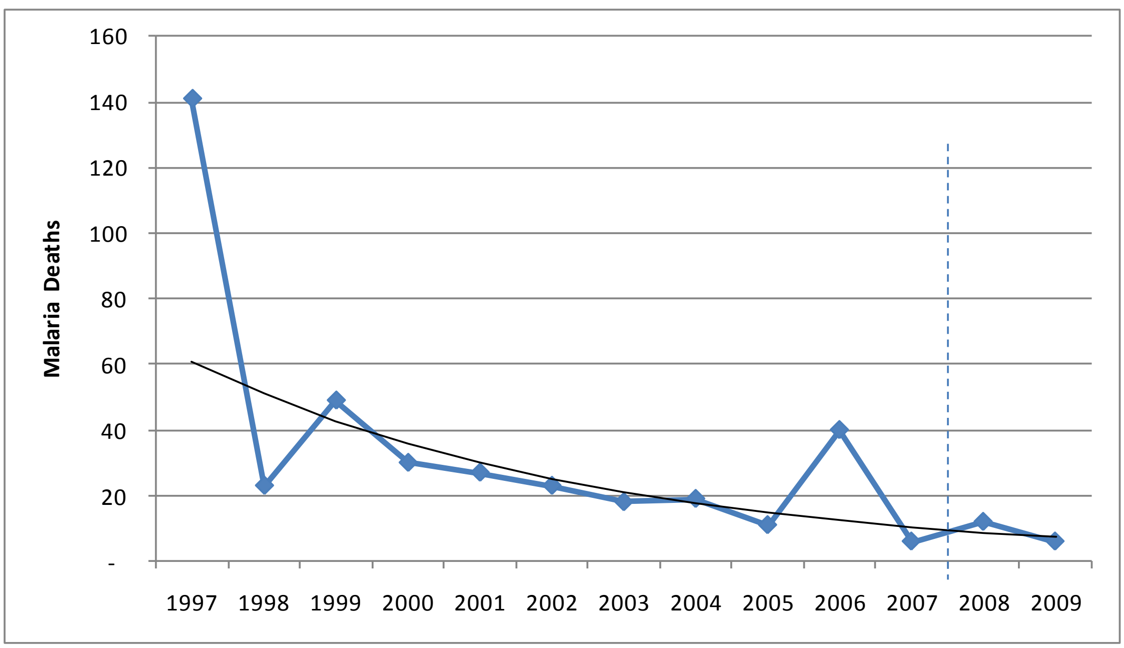
A similar trend is seen in deaths per year, shown in Figure 5 below. The analytic team performed additional analyses after normalizing cases and deaths by population, and obtained very similar qualitative results.

[9] World Health Organization, *World Malaria Report 2010*, p. 77–79.
[10] All data on which malaria related figures are derived from are shown in Appendix B.



Source: World Health Organization World Malaria Report 2010; Booz Allen analysis

Figure 4: Confirmed and Probable Malaria Cases in Botswana, 1997 to 2009 (Actual and 1997-2007 Exponential Trend Line)



Source: World Health Organization World Malaria Report 2010; Booz Allen analysis

Figure 5: Deaths from Malaria in Botswana, 1997 to 2009 (Actual and 1997-2007 Exponential Trend Line)

The downward-sloping convex shape of the curves seen in the figures above suggests that there is an exponential decrease in the number of malaria cases over time. In other words, the number of cases each year decreases by a fixed percentage (for example, 10 percent per year). A standard approach to estimate a baseline when such a relationship is present is to take the logarithm of the actual case and death data points, and to use standard linear regression techniques to find a best linear fit to the logarithmic data. The resulting line is then transformed back through exponentiation to generate a best-fit exponential curve.

The analytic team developed exponential fits for the Botswana data (shown in Appendix B). These exponential best-fit curves, shown as smooth black lines in Figures 4 and 5, are calculated using the data from 1997 to 2007 and are projected out to 2009.

The number of cases, or morbidity, seen in 2008 and 2009 are actually greater than those predicted based on data from before the NASA project was completed, although the differences are not statistically significant. Likewise, the number of deaths, or mortality, in 2008 was slightly higher than predicted by the exponential trend line, although not at a statistically significant level.[11] Only the actual death count for 2009 was below its forecast value, although this lower result was also not statistically significant, and represented only about one death in that year.

The team concluded that the incremental impact of the new NASA Earth observations was not distinguishable from normal variation in the predicted morbidity and mortality rates based on the available data. Botswana's efforts to control malaria improved their infection and death rates to low levels, leading to difficulty in discerning the impact from integration of NASA Earth observations.

B. Expert Opinion Analysis

The team separately applied the expert opinion methodology to develop an independent impact estimate. During the interview process, the experts reached a consensus that a maximum of 10 percent of the total effect could be attributed to NASA program.

Using the expert opinion methodology, the team multiplied the actual decrease in the number of deaths between 2007 and 2009 by the 10 percent maximum fraction assessed by the experts to estimate the maximum value of the impact of the NASA Earth observations. There was no net change in deaths between 2007 and 2009—6 in each year, with 12 in 2008— so the NASA impact estimate on death was zero. There were 2,105 fewer confirmed or probable cases of malaria in 2009 than in 2007, again with an increase in the intervening year 2008, leading to an estimate of the maximum impact of the NASA program of about 211 fewer cases in Botswana over the interval, or about 105 per year.

The results of these impact estimates are summarized in Table 1.

Table 1: NASA Project Annual Impact Estimates for Botswana using an Expert Opinion Methodology

Metric	Maximum Estimated Annual Reduction (Expert Opinion)
Cases	105
Deaths	0

C. Cost Effectiveness Review

The analytic team investigated financial effectiveness trends by dividing the reported malaria control expenditures by the number of cases, as well as the net reduction in cases per year.

Government expenditure data were sparse, but found from reliable sources for 2004, 2005 and 2008.[12] The results are shown in Table 2. The large variation in case reductions caused the expenditures per case reduction to vary wildly, and no trend was obvious. Nominal expenditures

[11] The difference could not be declared statistically significant because it was small relative to the standard deviation of the historical data.

[12] Includes government-only funds reported in the World Health Organization 2008 and 2009 World Malaria Reports. No other funding was reported.

per capita more than doubled over the period, suggesting that the government was devoting a larger fraction of resources to the program.

Table 2: Malaria Mitigation Expenditure Effectiveness Metrics for Botswana

Year	Expenditures (nominal US$)	Cases	Expenditures per case	Case reductions from previous year	Expenditures per case reduction	Population	Expenditures per capita
2004	$356,525	22,404	$15.91	<14>	<$25,466.07>	1,808,000	$0.20
2005	$391,131	11,242	$34.79	11,162	$35.04	1,840,000	$0.21
2008	$1,000,000	12,716	$78.64	<903>	<$1107.42>	1,952,000	$0.51

Source: World Health Organization World Malaria Reports (2008, 2009), Booz Allen analysis

D. Projection to Additional Countries in the Region

Members of the NASA project team suggested that project impacts were less likely to be estimated reliably in other Sub-Saharan countries because of data consistency and additional confounding policy, operational, and climatic factors. This hypothesis concerning data quality was confirmed as the analytic team applied the two methodologies to estimate the potential impact for 28 Sub-Saharan Africa countries listed in Figure 6, for which population and malaria case data were available for 2005–2008. The analytic team did not find consistent data on malaria deaths for these countries, so the analysis focused on data for cases of malaria.

Aggregate population and malaria case figures for the 28 countries are shown in Table 3. The reductions in cases per thousand for 2006 and 2007 were 1.8 percent and 2.4 percent respectively, but the 2008 reduction was a sharply stronger, at 13 percent.

Figure 6: Countries Included in the Expanded Impact Analysis

1. Angola
2. Burkina Faso
3. Burundi
4. Cameroon
5. Cape Verde
6. Central African Republic
7. Chad
8. Congo
9. Cote d'Ivoire
10. Eritrea
11. Ethiopia
12. Gabon
13. Gambia
14. Ghana
15. Kenya
16. Liberia
17. Madagascar
18. Malawi
19. Namibia
20. Niger
21. Nigeria
22. Rwanda
23. Sao Tome & Principe
24. South Africa
25. Swaziland
26. Uganda
27. Zambia
28. Zimbabwe

Table 3: Summary Malaria Data for Countries in Expanded Impact Analysis

Year	Population	Cases of Malaria	Cases per 1000	Annual rate Reduction
2005	585,192,657	58,756,183	100.4	--
2006	599,787,309	59,167,510	98.6	1.8%
2007	614,792,948	59,142,054	96.2	2.4%
2008	630,202,992	52,493,579	83.3	13.4%

Source: World Health Organization World Malaria Report (2009)

The analytic team applied the comparative impact approach with some caution, since there were only two yearly intervals with which to build a model, and only one data point from which to estimate potentially many effects. In the absence of more complete data, the team performed the analysis to obtain an order-of-magnitude result for comparison to the results based on an expert-opinion approach. The historical mean decrease in cases prior to 2008 was 2.1 percent per year,[13] but the 2008 decrease was 13.4 percent, which was much better (and statistically different) than the historical mean. The forecast number of cases for 2008 was approximately 59.4M cases, compared to an actual observed number of 52.5M, leaving a reduction of 6.9M cases potentially attributable to the NASA program.

Using the expert 10 percent attribution factor on annual decreases from the Botswana analysis, the estimated maximum impact was approximately 0.66M cases, an order of magnitude smaller than the estimate from the comparative impact approach. While these project impact estimates are not consistent for the greater Sub-Saharan region, they do suggest that the magnitude of the potential impact over the region is might be over a half million cases of malaria avoided per year. The results are shown in Table 4.

Table 4: NASA Project Annual Impact Estimates for Countries in Figure 6 using the Comparative Impact and Expert Opinion Methodologies

Metric	Estimated annual reduction (Comparative Impact Method)	Estimated annual reduction (Expert Opinion Method)
Cases	6,858,813	664,848

The extreme difference in these two estimates is likely due to the low historical reduction rate in the region. An average historical reduction in case per year of only 2 percent results in a forecast under the comparative impact method that is not much different from the previous year's actual observations. Thus, if actual reductions in a given year are more than a few percent, almost all of the avoided cases are attributed to the NASA project under this method. When applying the expert opinion method, only 10 percent of the actual reductions are attributed to the project, resulting in an estimate that is an order of magnitude smaller.

4. Findings and Conclusions

A. Summary of Findings

Two analytic methods were used to estimate the impact of integrating NASA Earth observations into MEWS on malaria in Botswana. The comparative impact method did not isolate a precise effect, while the expert opinion method suggested a decrease in the number of cases of malaria.

The first approach, using comparative impact analysis, was unable to identify statistically significant evidence of impacts on malaria cases or deaths in Botswana attributable to the NASA project in the two years following its implementation. Additionally, the available data provided inconclusive evidence about trends in the cost effectiveness of malaria control expenditures.

The second approach, employing expert opinion analysis, suggested an estimated average of approximately 105 cases per year avoided in Botswana as a result of the NASA project.

Applying the two methodologies to data for 28 Sub-Saharan countries provided broadly differing estimates of 6.9M and 0.66M potential case reductions due to the project, but suggested that the impact would be on the order of magnitude of a half million or more avoided cases per year.

B. Contextual Observations

In 2008, climate conditions were strongly conducive to malarial outbreaks in Botswana, and these are reflected in the data. That year the country received a considerable amount of rainfall, resulting in conditions ripe for potentially high levels of malaria transmission and deaths in many districts, including the central and southern parts of the country, such as the Bobirwa and Serowe/Palapye districts. Thus, Botswana should have experienced an increase in malaria based on climate factors alone.

[13] Standard deviation was 0.4 percent.

There is evidence that supports the assumption that NASA Earth observations are actively used by the decision makers in Botswana. Botswana's National Malaria Control Program has a long record of using early warning data to effectively reduce the incidence of malaria.[14] After a devastating regional malaria epidemic of 1996, the country reinvigorated its malaria control program through a range of initiatives including the development of an early warning system for epidemics. Currently, Botswana is committed to the Abuja Targets for Roll Back Malaria in Africa, which calls for countries in the Southern African Development Community to use malaria early warning technology to detect 60 percent of malaria epidemics within two weeks of onset, and respond to 60 percent of epidemics within two weeks of their detection. Thus, Botswana is a country with a strong commitment to reducing malaria and a stated policy of using early warning systems as a major part of its program.

C. Methodological Observations

The analysis findings were based on the two years of data available after completion of the Applied Sciences Program-funded project. They demonstrate the methodology and provide a first-look estimate, but could be refined as additional data become available in subsequent years.

To mitigate the challenge of limited data, multiple methods can be used and compared; for example, in the current analysis the analytics team supplemented the comparative impact approach with an expert opinion analysis. Consistency of results between different methods can provide a level of cross-validation in the absence of statistical significance of individual analyses.

Although the experts consulted reached consensus on impact estimates, they were not able to provide a consistent justification for these estimates. This lack of consensus suggests that the Earth science community might benefit from additional conversations and debate about analyzing and quantifying impacts and benefits.

The selection of Botswana was driven by its high data quality and its capacity to make use of applied science data in malaria programs. However, these factors indirectly militate against the impact of applied science data: countries that already have high quality data and mitigation programs may see less incremental value in new data products than more data-poor neighbors. Likewise, countries that have the will and organization to make use of the new data may already use existing data effectively, making the *potential*, if not realizable, incremental value of the new data lower than that for less organized or willful neighbors. Analysis teams should consider these factors when designing and executing impact analyses.

D. Conclusions

The socioeconomic impact of the NASA Project on *Enhancing USAID Malaria Early Warning Systems with NASA Earth Science Results* was not clearly identifiable in Botswana time-series data on cases and deaths. The lack of statistical identification does not imply that the project's overall impact was zero, though it does suggest that the likely impact was relatively small in countries in which malaria is relatively under control, such as Botswana. The potential impact in countries with more malaria cases and deaths is likely to be larger, though the actual impact may be limited by the ability of these countries to implement effective plans using the data, and the ability to measure impact may be limited by the quantity and quality of data. More work can be done within the Earth science community to better characterize and justify estimates of the benefits of their programs. Potential steps would include making early contact with the supported decision makers to gather requirements, validating the ability and willingness of decision makers to use the resulting data products, specifying impact metrics and data sources, following up at project completion to verify the products are being used by decision makers, and collecting and analyzing impact data over relevant time periods after the physical-science portion of the project is complete.

[14] See M. C. Thomson, et al., "Malaria early warnings based on seasonal climate forecasts from multi-model ensembles," *Nature* 439, 576-579 (2 February 2006) and Jonathan Cox and Tarekegn A. Abeku, "Early warning systems for malaria in Africa: from blueprint to practice," *Trends in Parasitology* Vol.23, No.6.

Appendix A: Acronyms

MEWS	Malaria Early Warning System
NASA	National Aeronautics and Space Administration
NRC	National Research Council
USAID	U.S. Agency for International Development
VOI	Value of Information
WHO	World Health Organization

Appendix B: Malaria Incidence Data for Botswana, 1997–2009

Botswana	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Reported Malaria Cases	101,887	59,696	72,640	71,403	48,237	28,858	22,418	22,404	11,242	23,514	16,983	17,886	14,878
Reported Malaria Deaths	141	23	49	30	27	23	18	19	11	40	6	12	6
Population	1,563,000	1,604,000	1,643,000	1,680,000	1,714,000	1,746,000	1,777,000	1,808,000	1,840,000	1,876,000	1,914,000	1,952,000	1,990,876
Malaria Cases per 1,000 people per year	6.52	3.72	4.42	4.25	2.81	1.65	1.26	1.24	0.61	1.25	0.89	0.92	0.75
Malaria Deaths per 1,000 people per year	0.09	0.01	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.00	0.01	0.00

Source: WHO World Malaria Report 2010,; Booz Allen analysis

Appendix C: Bibliography

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